Office of Naval Research Graduate Traineeship Award in Ocean Acoustics for Ankita Deepak Jain

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Grant Number: N00014-12-1-0411

OBJECTIVES

A primary goal of this research is to model biological clutter in the continental shelf environments of the ocean. We aim to do this by modeling scattered returns from fish shoals in continental shelf environments using a full field matched filter approach as well as its single frequency approximation. This will help in characterizing clutter and will help distinguish scattered fields of moving targets from stationary background reverberation and submerged targets in sonar data.

We aim to develop a unified theory and model for ocean reverberation dependent on seafloor parameters such as density, compressibility and coherence volume. We will use a full field matched filter approach and its time harmonic approximation to model reverberation from volume inhomogeneities. A Monte-Carlo approach based on the parabolic equation will be applied to model acoustic wave propagation in a fluctuating ocean waveguide. We aim at using the model to invert for these parameters and obtain accurate estimates by calibrating modeled returns with data collected during past Ocean Acoustic Waveguide Remote Sensing (OAWRS) experiments in 2003 and 2006 in the New Jersey continental shelf and the Gulf of Maine, respectively.

Another goal of this research is to test the hypothesis that inexpensive underwater acoustic measurements can be used to determine the wind speed and classify the destructive power of a hurricane with greater accuracy than standard satellite remote sensing techniques and with at least the same accuracy as hurricane hunting aircraft.

APPROACH

During the past OAWRS experiments in 2003 and 2006, we demonstrated that fish schools are the dominant cause of clutter in typical continental shelf environments [4, 5]. Based on the inverted parameters of fish such as neutral buoyancy depth, target strength and population density [6], scattered returns from fish distributions can be modeled and calibrated with measured returns. This model can then be extended to simulate wide-area images and movies, similar to those developed from collected data in the past [4, 5], showing temporal and spatial evolution of vast oceanic fish shoals.

We formulate a unified theory to model scattered returns from randomly distributed seafloor inhomogeneities in range-dependent ocean waveguides using the Rayleigh–Born approximation to

Report Documentation Page	*Form Approved* *OMB No. 0704-0188*

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1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
2012	**N/A**	**-**

4. TITLE AND SUBTITLE	
Office of Naval Research Graduate Traineeship Award in Ocean Acoustics for Ankita Deepak Jain	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Massachusetts Institute of Technology 77 Massachusetts Avenue, Room 5-212 Cambridge, MA 02139**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR’S ACRONYM(S)
	11. SPONSOR/MONITOR’S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release, distribution unlimited

13. SUPPLEMENTARY NOTES
The original document contains color images.

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			
unclassified	**unclassified**	**unclassified**	**SAR**	**4**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

Green's theorem [2]. This model will be implemented for a broadband source that uses matched-filter and beam forming to map the returns in range and bearing respectively. Calibration of modeled reverberation with data obtained during the OAWRS experiments enables estimation of seafloor parameters such as density, compressibility and coherence volume of inhomogeneities.

In the past, it has been shown that inexpensive underwater acoustic measurements can be used to determine the wind speed and classify the destructive power of a hurricane with greater accuracy than standard satellite remote sensing techniques [6]. The intensity of low frequency underwater sound measured directly below the hurricane is found to be approximately proportional to the cube of the local wind speed. In order to test this hypothesis, acoustic sensors will be deployed in the location on earth most frequented by hurricanes, and underwater noise data will be collected for a period of roughly one year. This noise data will then be correlated with local wind speed measurements and will be compared against data collected at another site, in the Mid Atlantic, to test the hypothesis developed by the PI.

WORK COMPLETED

In order to characterize the spatial and temporal behavior of biological clutter, we model the scattered returns from schools of randomly distributed fish based on the inverted parameters of fish obtained from the data collected during the 2006 OAWRS experiment in the Gulf of Maine [6]. The total scattered field from a school is calculated using a full field matched filter model that is capable of charting the scattered returns in range. The modeled returns are evaluated at different stages of the shoal formation, i.e. before, during and after shoal formation is complete. These stages are marked by different fish population densities and distributions of fish in the water column as observed during the OAWRS experiments [4, 5]. The returns at these stages are found to be in agreement with those in observed data collected in the OAWRS experiment in the Gulf of Maine. Further, we model the spatio-temporal behavior of fish population and demonstrate that coherent waves can lead to rapid formation of vast and dense continental shelf scale shoals containing millions of individuals, as was observed for shoaling Atlantic herring in the 2006 OAWRS experiment in the Gulf of Maine [4]. The behavior of each individual follows simple rules of animal behavior where its motion is influenced by its immediate neighbors [9] but together the fish population acts as a coherent mass that moves in an organized manner under some given initial conditions.

A full field matched filter approach is used to model scattered returns from random volume inhomogeneities in a range-dependent ocean environment [1]. Following the approach of Galinde et al. [2], a time harmonic approximation to the full field matched filter model is derived and is validated in Pekeris waveguide environment. Further, we introduce and validate approximations to the time harmonic expression for the total scattered field that speeds up the computation time significantly. The time-efficient time harmonic model is applied to the waveguide environments of the OAWRS experiments in the New Jersey continental shelf in 2003 and the Gulf of Maine in 2003, and is used to estimate a Rayleigh-Born seafloor parameter that is dependent on sediment properties such as density, compressibility and coherence volume of inhomogeneities, as well as the insonification frequency. This parameter is inverted for using the method of least squares by comparing seafloor reverberation data (415 Hz to 1325 Hz), collected during two OAWRS experiments with simulated reverberation using the time harmonic approximation. We show that for a typical sandy seafloor, the Rayleigh-Born parameter is inversely proportional to the insonification frequency and the coherence length scale of the volume inhomogeneities is smaller than the acoustic wavelength. Since this parameter is independent of the propagation effect and is solely dependent on scattering properties of volume

inhomogeneities in the seafloor, its estimation provides key information about seafloor reverberation, which is the most common limiting factor in long-range ocean sensing.

To obtain more data relating underwater sound and wind power in hurricanes, acoustic hydrophones were deployed for the second time in 2010 near Isla Socorro, Mexico as a part of a joint Ocean Acoustic Hurricane Classification experiment with the Mexican Navy. Isla Socorro, an island located a couple of hundred miles off the west coast of Mexico, is one of the most hurricane hit regions of the world and experiences an average of three hurricanes every year. Low frequency (<1000 Hz) underwater noise data was collected for a period of one year covering the entire hurricane season in the North Pacific Ocean near Mexico. Although, no hurricane passed near the island during the hurricane season of 2010-11, we were still able to correlate the recorded underwater noise data with wind speeds. The noise intensity is found to be approximately proportional to the cube of the local wind speed [8], which is consistent with the results obtained by Wilson and Makris [7]. We found that low frequency underwater noise was often contaminated by anthropogenic airgun signals [8]. We find that during the periods when airgun contamination exists, it is still possible to extract information about natural geophysical noise by analyzing time series in between pulses, modeling airgun source transmission through the ocean, and correlating measured noise with local wind speed. Mexican waters of the North Pacific Ocean are known to be wintering grounds for humpback whales [10]. During this experiment, many marine mammal vocalizations were recorded by the deployed hydrophones. We are in the process of categorizing these vocalizations according to their spectral and temporal characteristics, in order to potentially identify different types of marine mammal species that inhabit the waters near Isla Socorro.

IMPACT/APPLICATIONS

- A unified, range-dependent, broadband ocean reverberation model and calibration of modeled returns from seafloor sediments with past data will provide a tool for accurately estimating seafloor properties. This model helps distinguish between fluctuating returns due to clutter and statistically stationary seafloor reverberation, and enables efficient estimation of reverberation level in long range acoustic remote sensing in continental shelf environments.
- A model to calculate scattered returns from fish shoals will provide a tool to distinguish biological clutter from bathymetric features and intended targets. This model can also be used to study the spatio-temporal behavior of different fish species and marine organisms, which are a main cause of bioclutter in continental shelf environments.
- For wind speeds less than those in the hurricane range, low frequency underwater noise intensity is found to be approximately proportional to cube of the local wind speed. This result is consistent with the trend observed in the past for higher wind speeds in the hurricane range.

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